MADROÑO, Vol. 55, No. 3, pp. 223–237, 2008

VEGETATION CHANGE OVER SIXTY YEARS IN THE CENTRAL SIERRA NEVADA, CALIFORNIA, USA

JAMES H. THORNE[1], BRIAN J. MORGAN, AND JEFFERY A. KENNEDY
Department of Environmental Science and Policy,
University of California, Davis, CA, 95616, USA

ABSTRACT

In California, the Vegetation Type Map (VTM) project of the 1930's has provided valuable historical vegetation data. Albert Wieslander led this effort to survey the forests of California in the 1930's. His crews surveyed over 150,000 km², drawing detailed vegetation maps, taking 3000 photos and 17,000 vegetation plots. We developed a technique to digitize the Placerville 30′ quadrangle VTM, rendering it to a Geographic Information System (GIS). The map covers 2408.8 km² of the west slope of the Sierra Nevada. In this area VTM crews identified 59 dominant plant species and eight genera or land cover classes and mapped their distribution into 3422 polygons. They identified recently disturbed areas that covered 13.5% of the landscape. We compared the digital VTM quad to CALVEG, a satellite-derived vegetation map from 1996. Land cover change for California Wildlife Habitat Relationship (WHR) vegetation types had occurred on 42.1% of the area. WHR types with the largest gains were: Montane Hardwood, Douglas-Fir, and Annual Grassland. Low elevation hardwoods, particularly Blue Oak Woodland (dominated by *Quercus douglasii*, Fagaceae), chaparrals and upper elevation conifers were the types that lost the most area. Differences in mapping techniques are unlikely to be the cause of this change because the analysis used controlled for map-based errors. Potential causes of the observed change at these physiognomic levels of classification include human perturbation, succession, and climate change.

Key Words: Climate change, conifer loss, historical maps, land cover change, Sierra Nevada, VTM Project.

Historical landscape ecology interprets previous landscape conditions, which can provide a reference for assessment of changes in dominant vegetation, which are of particular interest for evaluation of ecosystem condition. These studies tend to be unique, in that interpretations of change are dependent on the data available, and methods for interpreting a data source are usually developed for each study. Notwithstanding, a wide variety of data have been used for these types of studies, for example: soil types, agricultural census, and weather station data have been analyzed to identify causes of the Dust Bowl (Cunfer 2002); historical distributions of tree species have been determined from locations of witness trees used for demarcating early ownership parcels (Cogbill et al. 2002); tree ring patterns have been used to establish historical climate and fire histories (e.g., Graumlich 1993); vegetation plot revisits have shown shifts in proportional species abundance along elevational gradients (Beckage et al. 2008; Kelly and Goulden 2008); and re-photography of historical photographs has been used to determine ecological trends (Veblen and Lorenz 1991).

Historical Overview

The Wieslander Vegetation Type Map (VTM) Project of California, USA was a United States Forest Service (USFS) effort to record the state's vegetation between 1928 and 1940 (Wieslander 1935a, 1935b, 1986; Griffin and Critchfield 1972). Headed by Albert Wieslander, the group took over 3000 photographs of vegetation, surveyed over 17,000 vegetation plots, recorded field notes, and mapped vegetation across about 35% of the state (~155,000 km²; Colwell 1977). The study covered predominantly USFS lands, but three national parks (Lassen, Yosemite, and Sequoia/Kings Canyon) were also surveyed using the same protocols (Griffin and Critchfield 1972; Wieslander 1986). The project also collected 25,000 plant specimens, housed at the Jepson Herbarium, University of California, Berkeley. These data collections form an important California legacy, and work is underway to systematically process them for preservation and state-wide analyses (Ertter 2000; Kelly et al. 2005; Thorne et al. 2006).

The VTM project produced vegetation maps for 215 quadrangles (55 7.5-minute, 88 15-minute and 72 30-minute), though portions of some quadrangles are missing or were not fully surveyed. Twenty three of the 30-minute maps were published by the University of California Press (Colwell 1977). Most of the published maps were destroyed before sale, although 20 sets were saved by P. Zinke (Wieslander 1986). These published maps have extensive margin notes but contain reduced floristic detail compared to the original survey maps.

[1] Email: jhthorne@ucdavis.edu

The VTM project data is the source for much of the current knowledge of tree and shrub species distribution in California. Elevational transect maps of vegetation (Critchfield 1971), and maps of the distribution of California trees (Griffin and Critchfield 1972), and range brushlands and shrubs (Sampson and Jespersen 1963) are based heavily on VTM data. The vegetation plots have received the most research attention to date, having been used in dissertations and published studies relating to both community classification (Jensen 1947; Allen et al. 1991; Allen-Diaz and Holman 1991), vegetation change (Bradbury 1974; Allen-Diaz and Holzman 1991; Holzman 1993; Minnich et al. 1995; Minnich and Dezzani 1998; Bouldin 1999; Taylor 2000; Franklin et al. 2004; Taylor 2004), and a study of carbon sequestration in soils (Fellows and Goulden 2008). The plots have been fully digitized and are available to the public online (Kelly 2008). The photos have been scanned by the University of California Bancroft Library and are available for viewing (Bancroft Library 2008). They have been used in at least two studies: changes in San Diego County vegetation (Dodge 1975) and forest changes at Lassen National Park (Taylor 2000).

At least three types of VTM maps were prepared: maps showing the locations of photographs, the locations of vegetation plots, and vegetation distribution. Ancillary information sometimes was recorded on an additional set of maps that shows stands of individual trees too small to map to polygons, routes taken, fire boundaries, and sawmill locations. Wieslander intended that plot data and vegetation maps to be used together, with the maps providing the extent and the plots providing composition and structure of the vegetation (Colwell 1977; Wieslander 1986). A number of early works presented such analyses (Weeks et al. 1934, 1943; Wieslander and Jensen 1946).

The VTM vegetation maps were used for land management analysis by USFS personnel, who would determine vegetation type extent by making a grid of points and overlaying it on the original VTM vegetation maps. Among their findings was that the lower edge of the western Sierra Nevada pine belt had moved upslope by an average of 305 m, representing a 16 km horizontal eastward displacement of the forest's western edge, recorded along 54 km of forest edge in El Dorado County (Weeks et al. 1934; Wieslander 1935c). This change, attributed to logging and which occurred between the 1894 gold rush and 1934, left a deforested area of 65,560 ha, much of which had been replaced by tree and shrub species associated with lower elevations.

Several studies used VTM vegetation maps as background information: Bradbury (1974) looked at changes in 134 vegetation plots and 25 landscape photos, with vegetation extents taken from the VTM vegetation maps for the Ramona Quadrangle in southern California; Freudenberger et al. (1987) examined changes in grasslands based on aerial photographs, with species identification based on VTM vegetation maps; and Davis et al. (1995; 1998) used scanned versions of the VTM maps to assist in attribution of satellite imagery-derived vegetations polygons for the Gap Analysis Program's (GAP) vegetation map of California. VTM species were used as GAP attributes if modern satellite image-derived shapes of vegetation polygons were similar to the original VTM polygon shapes.

Walker's (2000) dissertation assessed an early attempt to digitize VTM vegetation maps into a GIS. He used the VTM vegetation map from Yosemite National Park, which park scientist J. W. van Wagtendonk had digitized in the early 1980's. The digital version was produced on a digitizing table; the exact methods used are not known. Walker compiled the digitized line files he received from the park. He determined that the topographic map edition the VTM was drawn on (the base map), had non-systematic topographic mis-registration errors of up to 250 m when compared to a newer, digital version of the topography. He treated the problem by applying some 14,000 tie points to warp the historic maps (the park is spread over parts of four, 30-minute topographic quads) to the digital topography. Subsequently, species lists from modern surveyed vegetation plots were in good agreement with the vegetation of the VTM polygons they were located in.

This paper presents an analysis of change in vegetation from a 30-minute quadrangle in California's Sierra Nevada that was part of the Wieslander Vegetation Type Mapping (VTM) survey. We developed a technique for rendering the VTM vegetation maps to GIS, applied it to the quadrangle, and compared dominant vegetation type extents to a second vegetation map, mapped in 1996, comprising a time step of 62 yr.

Methods

We selected the VTM map for the Placerville 30-minute quadrangle, located in the Sierra Nevada (Fig. 1) and developed a method to digitize it, with the intent of examining changes in vegetation extent. The VTM map was originally surveyed according to a protocol which included: surveying from ridgelines; drawing vegetation polygons on the topographic base map; and recording the dominant plant species as codes in each polygon. Once species codes were recorded, field crews colored the polygons to match a habitat-level classification, drew cross-hatch lines to indicate burned or logged areas, and fixed the colors using a high quality benzene or gasoline

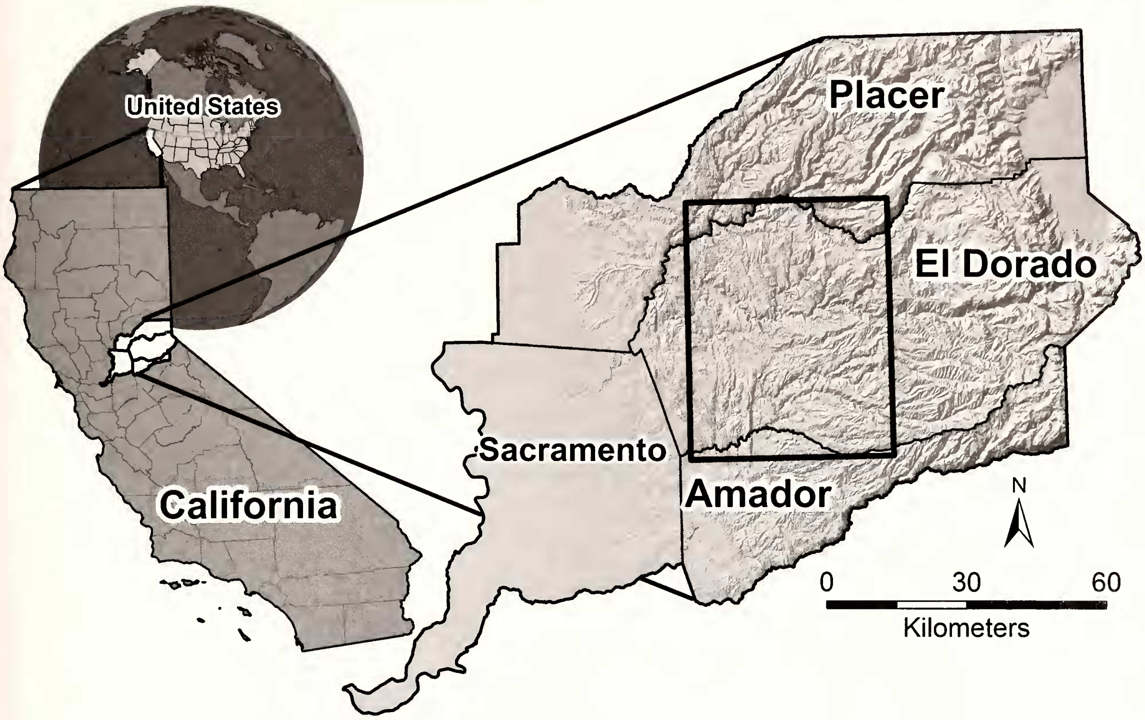

FIG. 1. Study area. Wieslander VTM crews surveyed the vegetation of the Placerville 30 min quadrangle, on the western slope of the Sierra Nevada, between 1931 and 1934.

(Wieslander et al. 1933). The vegetation recorded on the Placerville VTM quadrangle was mapped between 1931 and 1934 (Weeks et al. 1943). It was drawn directly on a 1931 edition of a United States Geological Survey (USGS) topographic quadrangle, which had been surveyed in 1887 and first published in 1893. Aerial photographs were not used. When finalized, the VTM map was cut into 16 sections (tiles) and glued to a canvas backing in blocks of four tiles, with spaces between the tiles where the map could be folded when taken in the field, which protected the maps from data loss along the creases.

Walker's dissertation (2000) indicated that bringing the VTM vegetation maps into alignment with modern topography would be time-intensive. Therefore, we used a different approach: to produce a VTM map to the level of spatial accuracy at which it was originally produced. Since the base topographic map upon which the VTM was drawn was surveyed at the turn of the century, we would reproduce the VTM map to those standards and not add the additional step of warping the image to get it to conform to later, improved, topographic accuracy. There were several reasons for selecting this approach. First, there was concern about introducing change to vegetation area estimates as the historic map would need to be warped to modern topography. Also, we were less concerned with identifying what change had happened on any 100 m^2 than in assessing change in dominant vegetation across the whole 2400 km^2 represented on the quadrangle. Future research can apply the additional processing required to replicate Walker's approach from our product, should that level of detail be needed, and funds are available.

Each of the 16 VTM tiles composing the original VTM map was scanned on a flatbed scanner at a 300 dots per inch (dpi) resolution. This produced 16 20-megabyte images. To assemble these tiles in a georeferenced manner, the first step was to register each vegetation tile onto a copy of the original topographic map. Thus, we obtained a scanned version of the 1931 USGS topographic quad (sheet scanned at the UC Santa Barbara, Alexandria Digital Library at 300 dpi), the same topographic quadrangle edition used by the VTM mapping crew.

Base Topographic Map Registration

The original projection of the USGS base topographic map is polyconic and uses Clarke's spheroid of 1866, map standards used by the USGS between 1886 and the late 1950's (U.S. Department of Commerce, Coast and Geodetic Survey 1917; Snyder 1982). This projection, which runs a meridian through the center of a map, was used because of its high level of precision on any given quad, although the assembly of multiple quads leads to high levels

of distortion. USGS field survey crews were able to construct such polyconic maps in the field, on which they recorded the topographic features (Gannet 1904; Beaman 1928). Using ERDAS IMAGINE (Leica Geosystem 2004), the scan of the USGS topographic quadrangle was transformed into polyconic projection using 16 control points placed at the intersections of the quad's latitude and longitude reference lines.

VTM Tile Registration

We re-assembled the VTM map to a single image by using ERDAS IMAGINE to register each of the 16 digital VTM tile images to the scanned topographic base map, using nine control points per tile. These control points were selected from features common to both maps, such as text, road intersections, and contour lines.

Vectorization and Polygon Attribution

Once the digital topographic base map and VTM tiles were in their native projection, it was possible to trace vegetation polygon boundaries. Several semi-automated vectorization techniques were tested, but these were not efficient due to the large number of other line features, such as elevation contours, on the map. Supervised image classification techniques also proved unsuitable as the coloring on the VTM tiles was smeared or deteriorated. We therefore used heads-up digitizing, using a Wacom Cintiq 21UX digitizing tablet (Wacom 2004), a LCD flat screen that permits the use of a digital pen to draw lines. Used in streaming mode, the pen assigns multiple vertices as a line is drawn. Linework was traced from the digital images at a resolution of 1:7000 or finer, a scale at which the thickness of the line being produced was equal to the lines being traced. The line production required that every dot in the dotted lines demarking vegetation polygons be intersected by the hand-drawn line. Once a shapefile of the linework was completed, polygons were built, and attribute columns added (ESRI 2004). Species codes written in each polygon were recorded in the order in which they appeared.

We used a species crosswalk (G. F. Hrusa, Senior Plant Taxonomist, CDFA, personal communication) to convert VTM-era species names to current scientific nomenclature (all authorities from Hickman 1993) for each species code on the map. Once the VTM species codes were entered, we used the ESRI ArcMap "Join" function to assign modern species names to the map codes. The resulting combinations of modern species names were then assigned to vegetation alliances, as documented in the Manual of California Vegetation (MCV) classification system (Sawyer and Keeler-Wolf 1995), and thence to California Wildlife Habitat Relationships (WHR) types (California Department of Fish and Game 2004). Spatial extents for each habitat type were then developed.

The VTM maps record dominant species as they occurred in each stand in order of percent cover, according to a standard set of cover thresholds specified in the VTM field methods manual (Wieslander et al. 1933). This recording of dominant species in whatever combinations they occurred provides data that can be translated into multiple classification systems. VTM polygons labeled with a single dominant species contain a minimum cover of 80% for that species. A polygon attributed with multiple species specifies each co-dominant cover at least 20% of the polygon. Species in VTM polygons can be grouped in one of four recognized growth form strata: trees, shrubs, herbs and grasses. Species from these classes can co-occur or be separated when classification to vegetation type is assigned.

One or two vegetation types occur in VTM polygons. Polygons with two types (mosaic polygons) contain contrasting growth forms, whose component sub-stands were either smaller than the minimum mapping unit, or in such a complex spatial pattern as to be impractical to map individually. In the case of a mosaic polygon, a species was listed if it covered a minimum of 20% of the mosaic sub-component, rather than 20% of the entire polygon. Mosaic polygons were labeled with species codes in a mix of horizontal and vertical orientations, so that the component vegetation types could be identified in a mosaic type. Unfortunately, the relative cover of each component type was not indicated in the attribute label. Consequently, we assigned the area of vegetation in mosaic polygons, with primary types receiving 2/3 and secondary types 1/3 of a polygon's area.

The VTM vegetation maps contain a large number of unique species combinations. To crosswalk these combinations to MCV alliances, we used the dominant species and disturbance information listed in each VTM map polygon, together with the MCV type descriptions and our knowledge of California vegetation patterns. We developed a set of rules to determine whether a polygon's vegetation was a mosaic or a single unit:

1) Grass was included in woodland types, but excluded from chaparral, forming a mosaic vegetation component when found with chaparral types.
2) In most cases, if conifers were present with oaks, oaks were assumed to be subdominants.
3) Riparian species were always considered a secondary type with other dominants when co-occurring.

4) Shrubs were assigned to (or excluded from) dominant conifer classes depending on disturbance, the species of shrub, and known general canopy density of the dominant trees. Generally, upper elevation conifer types include shrubs as sub-component (e.g., *Arctostaphylos patula*, Ericaceae), while the lower elevation pine types (all *Pinus sabiniana*, Pinaceae) exclude shrubs.
5) Species in the genus *Quercus* found in recently disturbed, chaparral shrub-dominated polygons were included as chaparral. If no disturbance was indicated, then chaparral and oak tree species were broken into mosaic types.

The MCV vegetation types were then cross-walked to WHR types, using a defined crosswalk from California Department of Fish and Game (2004). The WHR classification is based on physiognomic characteristics associated with a named dominant plant species, creating a habitat type often used to model vertebrate distributions in California.

Registration and Map Accuracy Assessment

Root mean square (RMS) error in meters was calculated for the process of registering VTM tiles to the topographic base map. Line vectorization RMS error was assessed by comparing the drawn lines to the registered VTM tiles. An estimate of RMS error to modern topography was calculated by registering 73 road locations to a modern digital coverage of roads (U.S. Department of Commerce 2001).

Comparison to Modern Maps

Two modern digital vegetation maps were available for comparison: the California Gap Analysis vegetation map (Davis et al. 1998), and the 1996 CALVEG land cover map (Schwind and Gordon 2001). We did not use the Gap Analysis vegetation map since many of its polygon attributes were derived from VTM maps. The CALVEG vegetation map source is independent, as its attributes were derived directly from 30 m resolution satellite imagery. CALVEG land cover classes are delineated through an automated process that is regionally calibrated and which produces 1 ha minimum size polygons labeled with WHR class land cover attributes.

Both VTM and CALVEG maps were re-projected to Albers Equal-Area projection, and the CALVEG map was clipped to the extent of the Placerville quadrangle. The vegetation type extent on each quad was summed by WHR type. Prior to comparison with the VTM map, the high polygon density in the CALVEG map was reduced by dissolving the borders between adjacent polygons that had the same WHR attributes.

Tabular summaries of WHR extents on each quad were compared in a non-spatial context to determine the major trends of land cover change. A graphic illustration of that change was produced by intersecting the maps, but the area extent reported represents independent measures of each map. We analyzed land cover change at the scale of the entire quad, developing a table showing the historic and current extent of each WHR type.

Results

VTM Map Processing

The VTM map covers 2408.8 km^2 and ranges from 200 m elevation in the southwest corner, on the Cosumnes River, to 1627 m in the northeast corner near Devil Peak and the Rubicon River. The registration of the topographic base map yielded a 7.4 m root mean square (RMS) error for control point error. The registration of the VTM tiles onto the base topographic map yielded a RMS error of 2.0 m. Therefore, geographic registration of the VTM map to the historic topographic map was completed with a RMS error $<$10 m. Comparison of the base topographic map to the modern digital roads map (U.S. Department of Commerce 2001), generated a RMS error of 263 m, indicating that by comparison to modern topography, any given point on the base map could be off by that amount.

VTM Map Content

The VTM mappers recorded 3422 polygons covering the 30-minute Placerville quad. The mean polygon size was 70.4 ha, with a standard deviation of 268.5 ha, minimum size of 5.8 ha and maximum size of 10,850 ha (Table 1). VTM mappers identified 59 species, one genus, two habitat types (Grass and Wet Meadow), and five non-vegetated or human-altered land cover classes (Table 2). One species code, thought to be a grass based on the colors in the legend, was not identified. It occupied 5.8 ha.

The VTM map contained 484 unique combinations of species that formed 45 MCV types. Those combinations were reduced to spatial extents for 25 WHR types (including "Unknown," which consisted of unreadable or untranslatable codes from the original maps; Table 3 and Fig. 2). WHR type Ponderosa Pine (dominant species, *Pinus ponderosa*) was the most broadly distributed WHR type (and species) on the map, occupying 36.9% of the landscape as the primary dominant tree, and occurring in several other WHR types as a secondary species. It also

TABLE 1. POLYGON NUMBERS BY SIZE CLASS FOR THE 1934 WIESLANDER MAP (VTM) AND THE 1996 CALVEG MAPS. Note the large difference in number of polygons, between the two sampling approaches.

Polygon size class (ha)	Number of polygons	
	VTM	CalVeg
0–0.25	1	0
0.5	0	36
1	4	61
2	94	3567
4	376	3655
8	522	2781
16	558	1848
32	577	939
64	470	478
128	388	256
256	236	95
512	119	53
1024	46	25
2048	25	10
4096	4	5
8192	1	1
16,384	1	0
32,768	0	0
Total	**3422**	**13,812**
Mean (ha)	70.4	17.4
Median (ha)	18.6	3.7
Standard Deviation (ha)	268.5	262.9
Minimum (ha)	0.1	0.252
Maximum (ha)	10,850.80	27,040.30

occupied the most polygons, occurring in 20.8% of all map units.

Quercus douglasii and *P. sabiniana*, species that occupy lower elevation foothills, occupied 13.4% of the landscape, appearing in three WHR types, Blue Oak Woodland, Blue Oak-Foothill Pine, and Foothill Pine (this last is a WHR class we created). Chaparral types occupied 13.2% of the landscape (including WHR type Closed-Cone Pine-Cypress); conifer types 52.3% (including the species *P. ponderosa*), and upper elevation hardwoods 9.4% (WHR types Montane Hardwood and Montane Hardwood-Conifer). The WHR type Annual Grassland occupied 8.1% of the landscape, and 2.5% was either urban or agriculture (WHR types Urban or Cropland; Table 3).

Of 3422 VTM polygons, 218 had a secondary vegetation type. Secondary types were predominantly chaparral types when conifers or hardwoods were the dominant type, or grasslands, when chaparral was the dominant type. The extents assigned to secondary types were one third of the area of the polygon they occurred in. Those spatial extents (Tables 3 and 4) were incorporated into the overall extents by WHR type, and occupy a total of 78.5 km^2. A total of 14.1% of the map's vegetation had recently been logged or burned (Table 3), with early seral Mixed Chaparral the most heavily represented WHR type.

VTM-CALVEG Differences in Mapped Vegetation

The CALVEG map identified 21 WHR types on the Placerville quad. It contained 44,630 polygons, which we reduced to 13,812 by dissolving borders between polygons with the same WHR class. The modified CALVEG coverage had an average polygon size of 17.4 ha with and a standard deviation of 262.9 ha (Table 1).

The difference between the VTM and CALVEG WHR extents totals 1049.7 km^2, or 42.1%, of the dominant land cover (Table 4). The largest WHR type increases were in Montane Hardwood (498.0 km^2), Douglas-Fir (210.2 km^2), and Montane Hardwood-Conifer (169.7 km^2). Annual Grassland increased by 50.6 km^2. Losses of WHR types were greatest for Ponderosa Pine, which decreased by 64.9%, losing some 570.4 km^2 (Fig. 3c), and Blue Oak-Foothill Pine, which lost 92.5% of its extent, 161.9 km^2 (Table 4).

Anthropogenic development of 42.8 km^2 of residential and 11.8 km^2 of man-made lakes, represent complete type conversion (habitat loss) of 2.3% of the region. Cropland decreased by 41.8 km^2 (1.1% of the region), suggesting some urban development may have gone onto cropland rather than into native vegetation.

There are two elevational patterns to the change, which generally conform to major elevation bands of vegetation found along the western flank of the Sierra Nevada. At lower elevations, below 700 m, Annual Grassland expanded, and low elevation hardwoods and conifers, particularly Blue Oak Woodland and Blue Oak-Foothill Pine, contracted (Figs. 3a, b). Above 700 m, Ponderosa Pine contracted while Montane Hardwood, Montane Hardwood-conifer and Douglas-Fir expanded (Figs. 3c, d).

Six condensed WHR types (Table 4, lower section, WHR types assigned to each group listed in parentheses) portray a slightly different view of the landscape. There was a decrease of 16.5 km^2 (85.2% of the type's extent) for Riparian habitats, a decrease of 385.1 km^2 of Conifer types, an increase of 667.7 km^2 of Upper Elevation Hardwood, and decreases of 156.6 km^2 of Lower Elevation Hardwood (including Foothill Pine), and 177 km^2 of Chaparral. Working Landscapes (grasslands and agriculture) increased 25.1 km^2. Six WHR classes mapped by the VTM survey were not present in the CALVEG map, and three WHR classes mapped by CALVEG, were not in the VTM (Table 4).

DISCUSSION

The two possible over-arching reasons for the observed change are 1) map-based errors, in

TABLE 2. SPECIES IDENTIFIED IN THE WIESLANDER VTM PLACERVILLE QUADRANGLE. Wieslander vegetation mappers identified 59 species (Authorities Hickman 1993), one genus, two habitats and five land cover classes on the 2408 km^2 of the Placerville quadrangle.

Species
Abies concolor
Acer macrophyllum
Adenostoma fasciculatum
Aesculus californica
Aira caryophyllea
Alnus rubra
Arctostaphylos manzanita
Arctostaphylos mewukka mewukka
Arctostaphylos nissenana
Arctostaphylos patula
Arctostaphylos viscida
Avena barbata
Avena fatua
Bromus carinatus carinatus
Bromus diandrus
Bromus hordeaceus
Calocedrus decurrens
Ceanothus cordulatus
Ceanothus cuneatus
Ceanothus integerrimus
Ceanothus leucodermis
Ceanothus parvifolius
Ceanothus spinosus
Ceanothus tomentosus
Cercocarpus betuloides
Cercocarpus ledifolius
Chamaebatia foliolosa
Cupressus macnabiana
Eriodictyon californicum
Erodium cicutarium
Heteromeles arbutifolia
Hypericum perforatum
Lithocarpus densiflorus
Lithocarpus densiflorus echinoides
Pellaea mucronata
Pinus attenuata
Pinus contorta murrayana
Pinus jeffreyi
Pinus lambertiana
Pinus monophylla
Pinus ponderosa
Pinus sabiniana
Prunus emarginata
Pseudotsuga menziesii menziesii
Pteridium aquilinum pubescens
Quercus berberidifolia
Quercus chrysolepis
Quercus chrysolepis nana
Quercus douglasii
Quercus durata
Quercus kelloggii
Quercus lobata
Quercus wislizeni
Quercus wislizeni frutescens
Toxicodendron diversilobum
Trifolium variegatum
Umbellularia californica
Vulpia myuros hirsuta
Genera and Physiognomic Types
Salix sp.
Grass
Wet Meadow
Unidentified Code
Hp
Land Cover Types
Barren
Cultivated
Residence
River
Rock

which case the question is how the errors were introduced; and 2) the dominant vegetation has changed, in which case the question becomes what are the drivers of the change. If the changes are due to map-based errors, those could derive from the processing of the historic data, vegetation type classification errors, or inaccuracies in the historic or modern maps. If the changes are real, they could be due to a variety of drivers, including human activity, climate, and their combined effects on fire, succession, and disease. This discussion reviews the possible sources of error first, followed by consideration of the measured vegetation change.

Potential Map-Based Errors

There has been much discussion of the accuracy of the VTM survey (Keeley 2004; Kelly et al. 2005; Kelly et al. 2008), and a legitimate question is to what degree can we rely on these maps to portray historical conditions? Two possible sources of error in the maps are registration error, due to inaccuracies in the topographic base map on which the VTM maps were drawn; and classification error, in which species combinations from the VTM maps are not correctly interpreted, or are not comparable to the CALVEG use of the WHR classification. The largest source of spatial error we could detect in the VTM vegetation maps comes from the underlying topographic maps, rather than from the vegetation mapping itself. We avoided georegistration issues that would be introduced by intersecting the maps from the two time periods, through tabular compilation of the vegetation type extents from each time period and comparison of the resulting tables. This did not permit us to follow the progression of change at any given location, but the overall extents of each vegetation type within the study area were comparable.

However, we present map overlays to help visualization of where the change for some habitat types occurred, and to illustrate the

TABLE 3. EXTENT OF WILDLIFE HABITAT RELATIONSHIP TYPES AND DISTURBANCE FOOTPRINTS ON THE PLACERVILLE QUADRANGLE IN 1934. Ponderosa pine was the dominant landcover type occupying the most terrain on the Placerville quadrangle around 1934. Extent of WHR types that had recently burned or been logged occupied 14.1% of the quad.

WHR type	Number of polygons	Area (ha)	Percent of total area	Early seral due to logging (ha)	Early seral due to burns (ha)	No disturbance measured (ha)
Ponderosa Pine (PPN)	714	88,875.7	36.91%	1989.1		86,886.6
Sierran Mixed Conifer (SMC)	200	30,227.1	12.55%			30,227.1
Montane Hardwood (MHW)	423	19,682.4	8.17%	225.3	839.3	18,617.8
Annual Grassland (AGS)	639	19,488.4	8.09%	30.3	8394.9	11,063.2
Blue Oak-Foothill Pine (BOP)	139	17,503.1	7.27%		3010.1	14,493
Mixed Chaparral (MCH)	201	13,965.3	5.80%	1722	10,236.4	2006.9
Blue Oak Woodland (BOW)	120	13,534.3	5.62%		1983.5	11,550.8
Chamise-Redshank Chaparral (CRC)	199	10,434.1	4.33%		115.6	10,318.4
Montane Chaparral (MCP)	223	6800.8	2.82%		3779.7	3021.1
Douglas-Fir (DFR)	27	6579.4	2.73%			6579.4
Cropland (CRP)	380	6105.5	2.54%		1.9	6103.6
Montane Hardwood-Conifer (MHC)	45	2868.3	1.19%		1195.7	1672.7
Montane Riparian (MRI)	30	1917.1	0.80%			1917.1
Foothill Pine (FHP)	7	1290.6	0.54%		459.8	830.8
Closed-Cone Pine-Cypress (CPC)	35	605.3	0.25%			605.3
Valley Oak Woodland (VOW)	17	485.6	0.20%		51.5	434.1
White Fir (WFR)	2	252.6	0.10%			252.6
Barren (BAR)	8	70.5	0.03%			70.5
Valley Foothill Riparian (VRI)	1	57.9	0.02%			57.9
Wet Meadow (WTM)	3	22.4	0.01%			22.4
Unknown (XXX)	5	15.3	0.01%			15.3
Eastside Pine (EPN)	1	10.9	0.01%			10.9
Urban (URB)	1	8.9	0.00%			8.9
Coastal Scrub (CSC)	1	6.2	0.00%			6.2
Lodgepole Pine (LPN)	1	4.2	0.00%			4.2
Total	**3422.00**	**240,811.70**	**100%**	**3966.70**	**30,068.30**	**206,776.70**

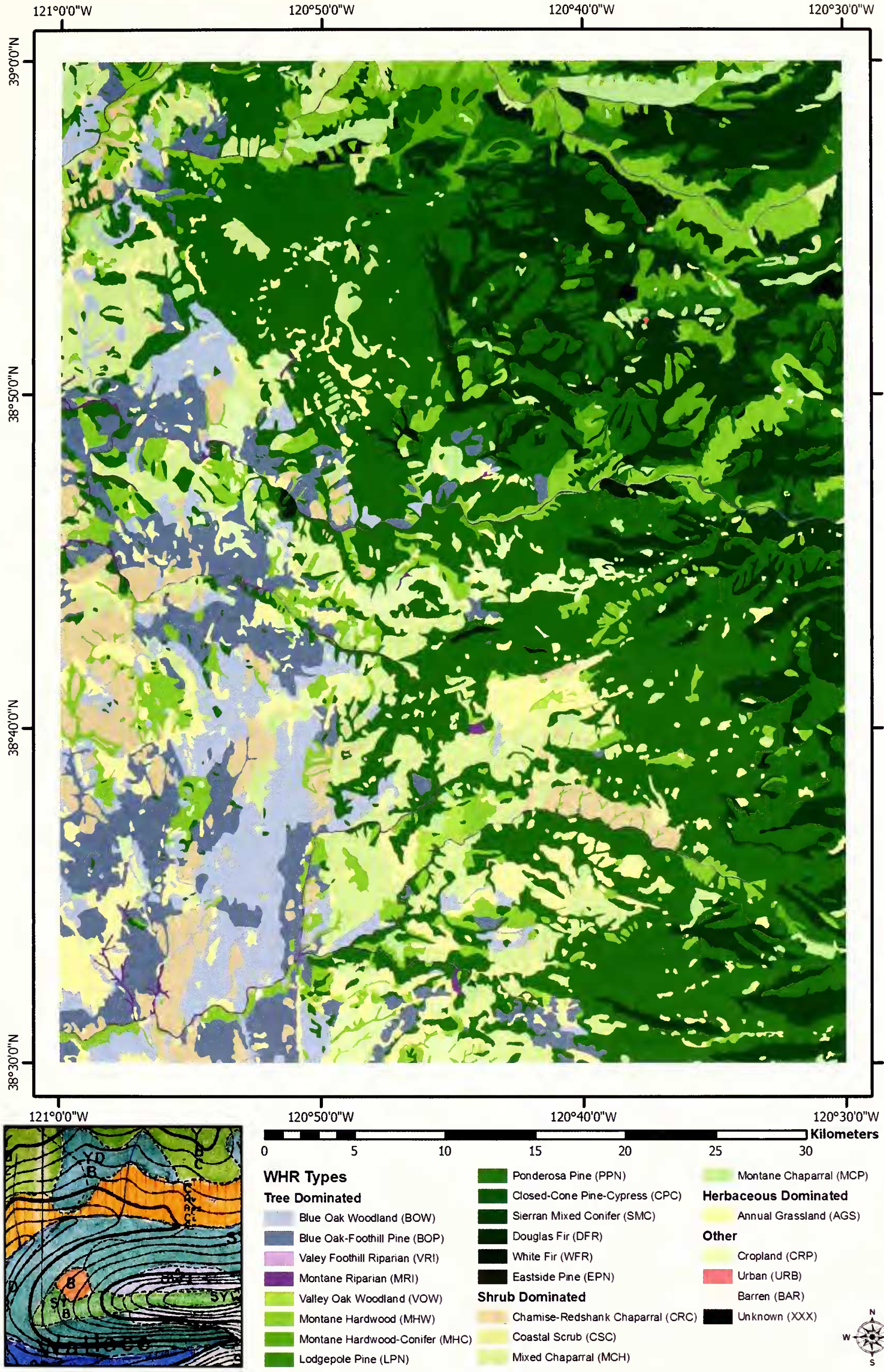

FIG. 2. The extent of California Wildlife Habitat Relationship landcover types on the Placerville quadrangle in 1934. We classed the historical species distributions mapped by VTM field crews into 25 Wildlife Habitat Types. The original map (insert) has the species codes used to identify the WHR types written in each polygon.

TABLE 4. RANKED ORDER CHANGE IN WILDLIFE HABITAT RELATIONSHIP LANDCOVER TYPE EXTENTS BETWEEN 1934 AND 1996. Overall change of WHR extents on the Placerville quad of types was ranked in descending order. Some WHR types were combined for ease of review (at bottom, combined types composition indicated by the WHR codes in parentheses).

WHR type	VTM area (ha)	VTM percent of total area	CALVEG area (ha)	CALVEG percent of total area	Area gained or (lost) (ha)	Percent of type gained or (lost)	Percent of map gained or (lost)
Montane Hardwood (MHW)	19,682	8.2%	69,481	28.8%	49,799	253.0%	20.7%
Douglas-Fir (DFR)	6579	2.7%	27,605	11.5%	21,026	319.6%	8.7%
Montane Hardwood-Conifer (MHC)	2868	1.2%	19,840	8.2%	16,971	591.7%	7.0%
Annual Grassland (AGS)	19,488	8.1%	24,551	10.2%	5063	26.0%	2.1%
Urban (URB)	9	0.0%	4298	1.8%	4289	48,373.2%	1.8%
Water (WAT)	0	0.0%	1185	0.5%	1185	0.0%	0.5%
Barren (BAR)	71	0.0%	961	0.4%	890	1262.9%	0.4%
Valley Oak Woodland (VOW)	486	0.2%	1338	0.6%	852	175.5%	0.4%
Eucalyptus (EUC)	0	0.0%	15	0.0%	15	0.0%	0.0%
Wet Meadow (WTM)	22	0.0%	35	0.0%	13	57.8%	0.0%
Coastal Oak Woodland (COW)	0	0.0%	6	0.0%	6	0.0%	0.0%
Lodgepole Pine (LPN)	4	0.0%	0	0.0%	−4	−100.0%	0.0%
Coastal Scrub (CSC)	6	0.0%	0	0.0%	−6	−100.0%	0.0%
Eastside Pine (EPN)	11	0.0%	0	0.0%	−11	−100.0%	0.0%
Unknown (XXX)	15	0.0%	0	0.0%	−15	−100.0%	0.0%
Valley Foothill Riparian (VRI)	58	0.0%	0	0.0%	−58	−100.0%	0.0%
White Fir (WFR)	253	0.1%	0	0.0%	−253	−100.0%	−0.1%
Blue Oak Woodland (BOW)	13,534	5.6%	13,211	5.5%	−323	−2.4%	−0.1%
Closed-Cone Pine-Cypress (CPC)	605	0.3%	195	0.1%	−410	−67.8%	−0.2%
Montane Riparian (MRI)	1917	0.8%	251	0.1%	−1666	−86.9%	−0.7%
Mixed Chaparral (MCH)	13,965	5.8%	11,719	4.9%	−2247	−16.1%	−0.9%
Sierran Mixed Conifer (SMC)	30,227	12.6%	27,727	11.5%	−2500	−8.3%	−1.0%
Cropland (CRP)	6106	2.5%	3554	1.5%	−2552	−41.8%	−1.1%
Montane Chaparral (MCP)	6801	2.8%	498	0.2%	−6302	−92.7%	−2.6%
Chamise-Redshank Chaparral (CRC)	10,434	4.3%	1260	0.5%	−9174	−87.9%	−3.8%
Blue Oak-Foothill Pine (BOP)	17,503	7.3%	1312	0.5%	−16,191	−92.5%	−6.7%
Ponderosa Pine (PPN)	88,876	36.9%	31,837	13.2%	−57,039	−64.2%	−23.7%
Foothill Pine (FHP)	1291	0.5%	-	-	-	-	
Total	**240,812**	**100%**	**240,878**	**100%**			**0.7%**

Combined categories (WHR types)	VTM area (ha)	VTM percent of total area	CALVEG area (ha)	CALVEG percent of total area	Area gained or (lost) (ha)	Percent gained or (lost)	Percent of map gained or (lost)
Upper Elevation Hardwood (MHW, MHC)	22,551	9.4%	89,320	37.1%	66,770	296.1%	27.7%
Working Landscapes (AGS, CRP)	25,594	10.6%	28,105	11.7%	2511	9.8%	1.0%
Riparian (WTM, VRI, MRI)	1940	0.8%	286	0.1%	−1653	−85.2%	−0.7%
Lower Elevation Hardwood (VOW, BOW, BOP)	31,523	13.1%	15,861	6.6%	−15,662	−49.7%	−6.5%
Chaparral (MCP, MCH, CRC, CPC)	31,805	13.2%	13,672	5.7%	−18,133	−57.0%	−7.5%
Conifer (DFR, SMC,PPN)	125,682	52.2%	87,169	36.2%	−38,513	−30.6%	−16.0%

largest patterns of land cover change. A rough estimate of the spatial registration errors is therefore of interest. The RMS error developed from registering the topographic base map to the digital roads map (U.S. Department of Commerce 2001) was 263 m. If we assume the spatial error to be spread equally among vegetation types, this approach permits an estimate derived by buffering VTM polygon boundaries with the RMS error, that 700 km^2 (34%) of the map is spatially precise. From a sampling perspective, 34% of the landscape is sufficient to capture the dominant trends. Note that in many areas of the map, the registration was considerably better than the average error.

The taxonomic component of the Wieslander surveys is the other potential source of error. However, this error is not likely to have been introduced by the VTM mappers themselves. The Placerville VTM map is floristically remarkable in its scope and detail. Wieslander wrote,

> "… the reliability of all future assumptions and conclusions to which any analysis of the VTM data may lead is dependent directly upon the character and quality of the field work. Therefore it is of utmost importance that this phase of the job be done strictly according to the rules set up and with consistency in their application." (Wieslander 1933).

Accordingly, the species recorded are likely correct. Error would more likely be introduced in the classification of species to MCV and WHR types. However, the VTM species lists and color codes on the VTM map allowed for rule-based crosswalking of the component VTM species into modern, pre-defined, classifications.

Classification error may also enter where the cover thresholds used to define CALVEG types differed from those used to define species in the VTM maps. CALVEG assigns transitions from grass to shrub, shrub to hardwood, and hardwood to conifer if >10% of the polygon contains the taller type, as opposed to >20% of a polygon being occupied by any co-dominant for a species to be listed in the VTM system. This generally means that a loss by a taller type to a shorter type is a conservative measure, whereas a gain in a taller type at the expense of a shorter type is less certain. For example, some of the measured loss of chaparral between time periods may be due to CALVEG classification of VTM Chaparral areas as hardwood. However, oaks commonly establish in chaparral, and so this potential error cannot be definitively identified because succession may actually be causing oak types to overtop chaparral on parts of the landscape. The large amount of the WHR type Montane Hardwood on the landscape is potentially partially due the CALVEG classification, which would favor this type, if only 10% of a brush field was in oaks that were discernable.

The indicated loss of conifers is particularly important to consider from the classification perspective. The loss appears real because the CALVEG map assigns conifer classes to less dense conifer stands than the VTM map. Therefore, the contemporary map is biased to producing more area in conifer than the VTM map, meaning a change showing reduction in conifers is more likely to be real. Since this is the biggest change on the landscape, we are confident it is real, where the shifts indicated in chaparral types are more problematic.

Land Cover Change

Loss of *Q. douglasii* extent (WHR types Blue Oak Woodland, Blue Oak-Foothill Pine, and Foothill Pine) and increase of grasslands (WHR type Annual Grassland) were the dominant trends at low elevation. The loss of *Q. douglasii* is also a transition from larger to shorter vegetation, making the estimate of change a conservative one. Potential explanations for these land cover changes include grazing, which impacts *Q. douglasii* recruitment (Hall et al. 1992) and which, in combination with pressure from wood cutting, contributes to *Q. douglasii* conversion to grassland. El Dorado County, which occupies most of the Placerville quad, has also experienced rapid population growth (10.6% between 2000 and 2004), with consequent development of low density rural residential areas (United States Census Bureau 2006) that could affect lower elevation vegetation. Chaparral types associated with lower elevations showed a reduction in extent, which have potentially transitioned to Montane Hardwood or Montane Hardwood Conifer.

The second major pattern of land cover change was at upper elevations, where the extent of *P. ponderosa*-dominated areas (WHR type Ponderosa Pine) was reduced by 64%, a loss of 570 km^2 (23.7% of the whole map). *Pinus ponderosa* areas were replaced by WHR type Montane Hardwood, whose dominant species is defined as *Quercus kelloggii*, Fagaceae, by WHR type Montane Hardwood-Conifer, where *Q. kelloggii* mingles with emerging conifers, and by WHR type Douglas-Fir (Fig. 3c for Montane Hardwood-Conifer, 3d for Montane Hardwood).

There are several possible explanations for the changes in the upper elevations. First, since *Q. kelloggii* is a subdominant tree under conifers, particularly *P. ponderosa*, the measured increase in hardwoods could be due to the loss of the conifer overstory canopy, where the understory remained in place. Second, all the oak tree species at this elevation stump sprout, and are often found co-mingled with chaparral shrubs. Hence,

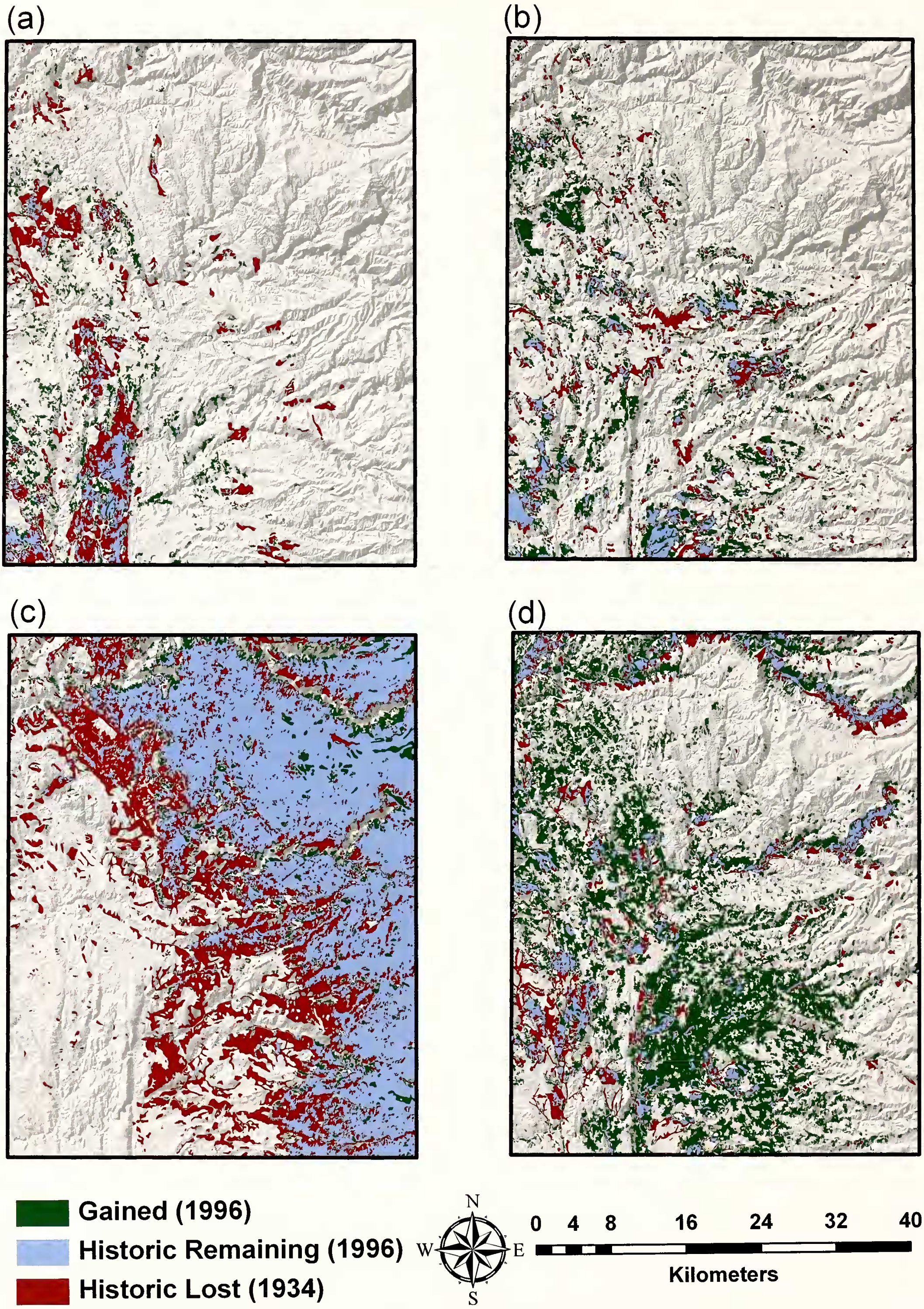

FIG. 3. The major changes in the WHR extents on the Placerville quadrangle between 1934 and 1996. Changes in WHR habitat types fall into distinct elevation zones. At lower elevations, Blue Oak Woodland and Blue Oak-Foothill Pine (3a) were greatly reduced, while Annual Grassland and Cropland increased (3b). At mid elevations, Ponderosa Pine, the lowest growing of the Montane WHR conifer-dominated types, showed the greatest reduction (3c; red indicates Ponderosa Pine WHR type lost over time, blue indicates historic extent remaining and green the

some expansion in hardwoods could be the result of succession, where oaks in brush fields following fire or clear cutting of conifers overtop the shrubs they are growing with. The numbers suggest some of this is occurring due to decreasing chaparral extents. This pattern of lower *P. ponderosa* replaced by oaks was also observed in 1934, when (Weeks et al. 1934) estimated that the coniferous belt had previously (in 1850) extended as low as 305 m, but had retreated greatly uphill by the time of his survey. While *P. ponderosa* has been replaced by hardwoods at lower elevations, it has been replaced by *Pseudotsuga menziesii* var. *menziesii*, which has grown into it at higher elevations, changing the WHR type (Fig. 3c).

Two overlapping processes may be driving pattern on this landscape: disturbance, which removes structure and vegetation types; and subsequent succession with potentially altered pathways reflecting new climatic and disturbance regimes, where a distinct change in potential vegetation is manifested as a different vegetation type in the current map, from what was present in the 1930's. Succession may not ultimately result in the re-establishment to the vegetation mapped in the 1930's, or it may take longer to return to the historic type due to climatic shifts. Temperature measurements from nearby Placerville indicate that minimum monthly temperatures there have been warming at the rate of 0.089° Cyr^{-1} ($R^2 = 0.71$, $P < 0.001$) between 1960 and 2000 (data from National Climate Data Center 2005). Such a shift could potentially contribute to vegetation change by making re-establishment conditions post-disturbance less suitable for prior vegetation, or make the time required for successional regeneration longer, which in turn increase the probability of another disturbance before the historic type is reached.

Conclusion

This study demonstrates the utility and importance of historical vegetation maps. While their development is technically challenging, the potential insights that can be derived are of lasting import. The Placerville VTM quadrangle contains information of about 59 species, which is better taxonomic resolution than any comparable modern vegetation map. While there are legitimate concerns over the use of VTM vegetation maps to detect change, at least at the landscape scale, they provide information available from no other source. It is hoped that this presentation of the map development methods and their application will lead to interest in developing this data for the remaining regions available in California.

Acknowledgments

This study was made possible by grant # PNV 03-JV-11261979-162 from the US Forest Service Pacific Northwest Research Station, the western regional science coordinator for the US Forest Service; and by grant # 500-02-004 from the California Energy Commission. Dr. Barbara Allen-Diaz, UC Berkeley, permitted access to the VTM collection and offered useful commentary. Dr. Fred Hrusa assisted with the development of the species lookup table, Dr. Maggi Kelly, Ken-Ichi Ueda, and Dave Shaari, UC Berkeley, assisted with technical problems, and staff of the UC Berkeley Geology Library and the UC Santa Barbara Alexandria Digital Library assisted with scanning maps. We thank Aaron Fulton, Camille Kustin, Alexa Callison-Burch, and Myra Kim for their patient work digitizing and attributing the original map. We thank Dr. Jim Quinn, UC Davis, for providing the space to house computers and host the work.

Literature Cited

Allen, B. H., B. A. Holzman, and R. R. Evett. 1991. A classification system for California's hardwood rangelands. Hilgardia 59:1–45.

Allen-Diaz, B. H. and B. A. Holzman. 1991. Blue oak communities in California. Madroño 38:80–95.

Bancroft Library. 2008. Wieslander Vegetation Type Maps and Photographs website. Available at: http://www.lib.berkeley.edu/BIOS/vtm/.

Beaman, W. M. 1928. Topographic instructions of the United States Geological Survey. Department of Interior, U.S. Geological Survey, United States Government Printing Office, Washington, DC.

Beckage, B., B. Osbourne, D. G. Gavin, C. Pucko, T. Siccama, and T. Perkins. 2008. A rapid upward shift of a forest ecotone during 40 yr of warming in the Green Mountains of Vermont. Proceedings of the National Academy of Sciences 105:4197–4202.

Bouldin, J. R. 1999. Twentieth-century changes in forests of the Sierra Nevada, California. Ph.D. dissertation. University of California, Davis, CA.

Bradbury, D. E. 1974. Vegetation history of Ramona Quadrangle San Diego County, California (1931–1972). Ph.D. dissertation. University of California, Los Angeles, CA.

California Department of Fish and Game. 2004. The California wildlife habitat relationships system. California Department of Fish and Game, Sacramento, CA. Available at: http://www.dfg.ca.gov/whdab/html/wildlife_habitats.html

Cogbill, C. V., J. Burk, and G. Motzkin. 2002. The forests of presettlement New England, USA: spatial and compositional patterns based on town proprietor surveys. Biogeography 29:1279–1304.

Colwell, W. L. 1977. The status of vegetation mapping in California today. Pp. 195–220 *in* M. G. Barbour and J. Majors. (eds.), Terrestrial

←

new extent of a combination of Ponderosa Pine, Douglas-Fir, Sierra Mixed Conifer, and Lodgepole Pine WHR types), while Montane Hardwood showed the greatest increase, replacing much of the Ponderosa Pine (3d).

vegetation of California. John Wiley & Sons, New York, NY.

CRITCHFIELD, W. B. 1971. Profiles of California vegetation. Research Paper PSW-76. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

CUNFER, G. 2002. Causes of the dust bowl. Pp. 93–103 *in* A. K. Knowles (ed.), Past time, past place, GIS for history. ESRI Press, Redlands, CA.

DAVIS, F. W., P. A. STINE, D. M. STOMS, AND A. D. HOLLANDER. 1995. Gap analysis of the actual vegetation of California: 1. The southwestern region. Madroño 42:40–78.

———, D. M. STOMS, A. D. HOLLANDER, K. A. THOMAS, P. A. STINE, D. ODION, M. I. BORCHERT, J. H. THORNE, M. V. GREY, R. E. WALKER, K. WARNER, AND J. GRAAE. 1998. The California gap analysis project: final report. University of California, Santa Barbara.

DODGE, J. M. 1975. Vegetation changes associated with land use and fire history in San Diego County. Ph.D. dissertation. University of California, Riverside, CA.

ERTTER, B. 2000. Our undiscovered heritage: past and future projects for species-level botanical inventory. Madroño 47:237–252.

ESRI. 2004. Arc Info. Geographic Information System software, Redlands, CA.

FELLOWS, A. W. AND M. L. GOULDEN. 2008. Has fire suppression increased the amount of carbon stored in western U.S. forests? Geophysical Research Letters 35:L12404, doi:10.1029/2008GL033965.

FRANKLIN, J., C. L. COULTER, AND S. J. REY. 2004. Change over 70 yr in a southern California chaparral community related to fire. Journal of Vegetation Science 15:701–710.

FREUDENBERGER, D. O., B. E. FISH, AND J. E. KEELEY. 1987. Distribution and stability of grasslands in the Los Angeles Basin. Bulletin of Southern California Academy of Sciences 86:13–26.

GANNET, S. S. 1904. Geographic tables and formulas. United States Geological Survey, Department of Interior, Government Printing Office, Washington, DC.

GRAUMLICH, L. J. 1993. A 1000-year record of temperature and precipitation in the Sierra Nevada. Quaternary Research 39:249–255.

GRIFFIN, J. R. AND W. B. CRITCHFIELD. 1972. The distribution of forest trees in California. Research Paper PSW-82. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

HALL, L. M., M. R. GEORGE, D. D. MCCREARY, AND T. E. ADAMS. 1992. Effects of cattle grazing on blue oak seedling damage and survival. Journal of Range Management 45:503–506.

HICKMAN, J. C. (ed). 1993. The Jepson manual: higher plants of California. University of California Press, Berkeley, CA.

HOLZMAN, B. A. 1993. Vegetation change in California's blue oak (*Quercus douglasii*) woodlands 1932–1992. Ph.D. dissertation. University of California, Berkeley, CA.

JENSEN, H. A. 1947. A system for classifying vegetation in California. California Fish and Game 33:199–266.

KEELEY, J. E. 2004. VTM plots as evidence of historical climate change: goldmine or landmine? Madroño 51:372–378.

KELLY, A. E. AND M. L. GOULDEN. 2008. Rapid shifts in plant distribution with recent climate change. Proceedings of the National Academy of Sciences 105:11823–11826.

KELLY, M., B. ALLEN DIAZ, AND N. KOBZINA. 2005. Digitization of a historic dataset: the Wieslander California Vegetation Type Mapping Project. Madroño 52:191–201.

———. 2008. The Wieslander Vegetation Type Mapping Webpage. http://vtm.berkeley.edu/.

———, K. I. UEDA, AND B. ALLEN DIAZ. 2008. Considerations for ecological reconstruction of historic vegetation: analysis of the spatial uncertainties in the California Vegetation Type Map dataset. Plant Ecology 194:37–94.

LEICA GEOSYSTEM. 2004. ERDAS IMAGINE. Software. Norcross, GA.

MINNICH, R. A., M. G. BARBOUR, J. H. BURKE, AND R. F. FERNAU. 1995. Sixty years of change in Californian conifer forests of the San Bernardino Mountains. Conservation Biology 9:902–914.

——— AND R. J. DEZZANI. 1998. Historical decline of coastal sage scrub in the Riverside-Perris Plain, California. Western Birds 29:366–391.

NATIONAL CLIMATE DATA CENTER. 2005. United States Historical Climatology Network (USHCN). Available at: http://www.ncdc.noaa.gov/oa/climate/research/ushcn/ushcn.html

SAMPSON, A. W. AND B. S. JESPERSEN. 1963. California range brushlands and browse plants. University of California, Division of Agriculture and Natural Resources, Oakland, CA.

SAWYER, J. O. AND T. KEELER-WOLF. 1995. A manual of California vegetation. California Native Plant Society, Sacramento, CA.

SCHWIND, B. AND H. GORDON. 2001. CALVEG geobook: a comprehensive information package describing California's wildland vegetation, version 2. U.S.D.A. Forest Service, Pacific Southwest Region, Remote Sensing Lab, Sacramento, CA.

SNYDER, J. P. 1982. Map projections used by the U.S. Geological Survey. Geological Survey Bulletin 1532. United States Government Printing Office, Washington, DC.

TAYLOR, A. H. 2000. Fire regimes and forest changes in mid and upper forests of the southern Cascades, Lassen Volcanic National Park, California, U.S.A. Journal of Biogeography 27:87–104.

TAYLOR, R. S. 2004. A natural history of coastal sage scrub in southern California: regional floristic patterns and relations to physical geography, how it changes over time, and how well reserves represent its biodiversity. Ph.D. dissertation. University of California, Santa Barbara, CA.

THORNE, J. H., R. KELSEY, J. HONIG, AND B. MORGAN. 2006. The development of 70 yr old Wieslander Vegetation Type Maps and an assessment of landscape change in the central Sierra Nevada. California Energy Commission. CEC 500-2006-107. PIER Energy Related Environmental Program, Sacramento, CA.

UNITED STATES DEPARTMENT OF COMMERCE, COAST AND GEODETIC SURVEY. 1917. Geodesy: tables for a polyconic projection of maps, based upon

Clarke's reference spheroid of 1866. Fourth edition. Special Publication No. 5. Department of Commerce, Washington Government Printing Office, Washington, DC.

United States Department of Commerce. 2001. TIGER\Line files, roads. Department of Commerce, Washington, DC.

United States Census Bureau. 2006. State and County Quick Facts. Census Bureau, Washington, DC. Available at: http://quickfacts.census.gov/qfd/states/06/06017.html

Veblen, T. T. and D. C. Lorenz. 1991. The Colorado Front Range: a century of ecological change. University of Utah Press, Salt Lake City, UT.

Wacom. 2004. Digitizing screen that uses digital pen. Wacom Technology, Vancouver, WA.

Walker, R. E. 2000. Investigations in vegetation map rectification, and the remotely sensed detection and measurement of natural vegetation changes. Ph.D. dissertation. University of California, Santa Barbara, CA.

Weeks, D., A. E. Wieslander, and C. L. Hill. 1934. The utilization of Eldorado County Land. University of California Bulletin 572. Giannini Foundation, University of California, Berkeley, CA.

———, ———, H. R. Josephon, and C. L. Hill. 1943. Land utilization in the northern Sierra Nevada. Agricultural Experiment Station, University of California College of Agriculture, Berkeley, CA.

Wieslander, A. E. 1935a. A vegetation type map for California. Madroño 3:140–144.

———. 1935b. First steps of the forest survey in California. Journal of Forestry 33:877–884.

———. 1935c. The Forest Survey in California. R publication Series. California Forest and Range Experiment Station, Berkeley, CA.

———. 1986. A.E. Wieslander, California forester: mapper of wildland vegetation and soils (an oral history conducted in 1985 by Ann Lange). Regional Oral History Office, Bancroft Library, University of California, Berkeley, CA.

——— and H. A. Jensen. 1946. Forest areas, timber volumes, and vegetation types in California. Forest Survey Rel. No. 4. Forest and Range Experiment Station, Berkeley, CA.

———, ———, and H. S. Yates. 1933. California vegetation type map: Instructions for the preparation of the vegetative type map of California. Unpublished USDA Forest Service report on the file in library at Yosemite National Park, Yosemite Valley, CA.